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CATEGORY II/III TEST OF THE AN/GSN-5A

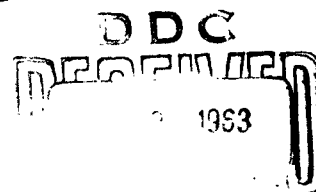
James R. Prichard

TECHNICAL DOCUMENTARY REPORT NO. RADC-TDR-63-166

April 1963

Control Systems Laboratory
Rome Air Development Center
Research and Technology Division
Air Force Systems Command
Griffiss Air Force Base, New York

431L System



FOR ERRATA

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THE FOLLOWING PAGES ARE CHANGES

TO BASIC DOCUMENT

AD 405 46

ERRATA

RADC-TDR-63-166

CATEGORY II/III TEST OF THE AN/GSN-5A

James R. Prichard

Page 1, line 10: *For* 100 automatic flared landings with F-30 and F-86 types of aircraft.
Read 100 automatic flared landings with an F-86 type of aircraft.

Page 1, line 34: *For* With 90 days of five skill level factory training, a maintenance technician was found sufficiently trained to perform most of the field maintenance required. *Read* With 90 days of factory training a five skill level Air Force maintenance technician would be capable to perform most of the field maintenance required.

Page 15, line 5: *For* Figure 4. *read* Figure 14.

Page 18, line 10: *For* 53 days *read* 53 hours.

Page 21, line 37: *For* Pindle ring mounts *read* Pintle ring mounts.

Page 21, line 37: *For* pindle rings on all *read* pintle rings on all.

Page 21, line 39: *For* pindle hook. *read* pintle hook.

Page 22, line 36: *For* norma *read* normal.

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ABSTRACT

The Landing Control, Central, AN/GSN-5A is a ground-based, final approach navigation system providing three basic approach and landing techniques. These include completely automatic control, cross-pointer guided approach, and talkdown. These techniques used singularly or in combination maintain aircraft surveillance and guidance information to touchdown.

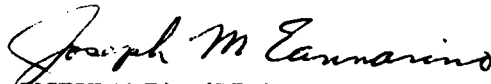
Test aircraft used in the Category II Program were an F-102A, KC-135 and an RB-57. In Category III test aircraft were an F-105, B-57, B-52, T-33, T-38, B-47, F-106, F-101, and an F-100. The F-102A was the primary automatic landing test vehicle.

Test results are presented in the form of graphs, tables, and general comments and form a basis for the conclusions and recommendations.

PUBLICATION REVIEW

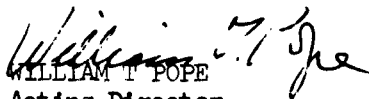
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CATEGORY II/III TEST OF THE AN/GSN-5A

I. HISTORY

The AN/GSN-5A was developed by the AF/431L System as an interim equipment to satisfy GCA for an automatic all-weather landing system. The main reason for selecting the GSN-5A type of equipment is its success as a landing aid in the Bureau of Ships Research and Development Program. An experimental model of this system, AN/SPN-10, was tested at Griffiss Air Force Base during the fall of 1955 to determine its usefulness as an Air Force landing aid. The SPN-10, as configured by the Navy, contained a carrier type of glide path reference and an analog data link. The main questions to be solved by the first Air Force test were (1) can a flareout glide path be implemented and (2) can a digital data link AN/GSN-5 be used to control an aircraft. These two factors were satisfactorily tested by successfully performing 100 automatic flared landings with F-30 and F-86 types of aircraft.

After this test period, specifications were prepared for an Air Force version of this SPN-10. The first model, called the AN/GSN-5, was produced in 1960. At that time, it was delivered to NAFEC for a combined AF/FAA test program.

The second Air Force model of an interim landing equipment was fabricated in 1961 and designated the AN/GSN-5A. This model was identical to the first except it contained a K_a -band beam-coding, a two-pulse data link, and was packaged in four-wheels project concept; that is, 8 x 11 trailers for the control and communications vans. This model was delivered to the Air Force in July 1961. An initial flight program was initiated at the contractor's facilities. A total of 128 automatic landings of an aero-commander aircraft were achieved between May 1961 and September 1961. Beacon track beam coding was successfully demonstrated during this test.

After the program at the contractor's plant, a special operational requirement was generated for use of the GSN-5A. To verify its capability for this requirement, the equipment was moved to McGuire Air Force Base in November 1961 for a three-month test program. Basically, the purpose of this program was to determine the GSN-5A's operational suitability and to develop operational procedures for use of the GSN-5A in a high-density real air traffic environment.

The tests at McGuire Air Force Base were all of the nonautomatic type; that is, GCA talkdown or air-derived ILS needle display. Also, test aircraft were not specifically equipped. Scintillation of radar was found to limit manual and automatic control on unmodified aircraft to a lower limit of 100 feet in altitude and 1/4-mile in range. Equipment reliability was found to be excellent and with training of approximately two weeks, a GCA controller could operate the GSN-5A. With 90 days of five skill level factory training, a maintenance technician was found sufficiently trained to perform most of the field maintenance required.

The contractor in-plant test and the McGuire test did not contain all the desired Category II/III test objectives. Therefore, the 431L SPO recommended and received approval to conduct an Air Force evaluation of the GSN-5A at Griffiss Air Force Base. This test was intended to determine if the equipment performed in accordance with its desired objectives as stated in Air Force Exhibit RDZSEW-23 and to determine any additional limitations and improvements required in any future procurement of this type of equipment.

II. EQUIPMENT DESCRIPTION

A. AN/GSN-5A

The Landing Control, Central, AN/GSN-5A is a ground-based, final approach navigation system providing three basic approach and landing techniques; namely, completely automatic control, cross-pointer guided approach, and talkdown. These techniques may be used singularly or in combination. In all cases, however, aircraft surveillance and guidance information are maintained to touchdown.

The AN/GSN-5A approach and landing techniques available for a particular aircraft type are dependent upon the existing airborne equipment. Completely automatic control is available only if the aircraft is equipped with an attitude-hold autopilot and a suitable data link. If the aircraft possesses only a data link, the AN/GSN-5A system can be employed for cross-pointer guided approaches. The radio aids, normally available in present aircraft, are sufficient for talkdown approaches, and are used to supplement both the completely automatic and cross-pointer modes of operation. To realize the approach and landing accuracy inherent in the AN/GSN-5A system, all aircraft must incorporate a strong-point target for the radar in the form of a corner reflector or radar beacon antenna.

The precision automatic tracking radar, Figure 1, illuminates a preselected area in space known as the acquisition gate. As the aircraft passes through the gate, the radar locks onto and tracks the aircraft's corner reflector or radar beacon antenna. A set of rectangular coordinates consisting of range, altitude, and lateral displacement are formed in the position computer relative to the radar gimbal axes. These coordinate data are then fed into the control computer where they are compared with the desired aircraft position to establish vertical and lateral position error signals. The manner in which these error signals are used is dependent upon the mode of AN/GSN-5A operation.

In the automatic control mode, the vertical and lateral position error signals are used by the control computer to compute the pitch and bank commands required to direct the aircraft to and along the desired flight path. Suitable filtering, limiting, differentiating, and integrating operations are performed during the generation of these commands to obtain responses compatible with the maneuverability of the aircraft and the geometry of the flight path. The commands are then supplied to the data link, coded, and transmitted to the aircraft. In the aircraft, the commands are also impressed upon the ILS glide-slope and localizer indicator for use by the pilot for command-monitoring or flight-director information.

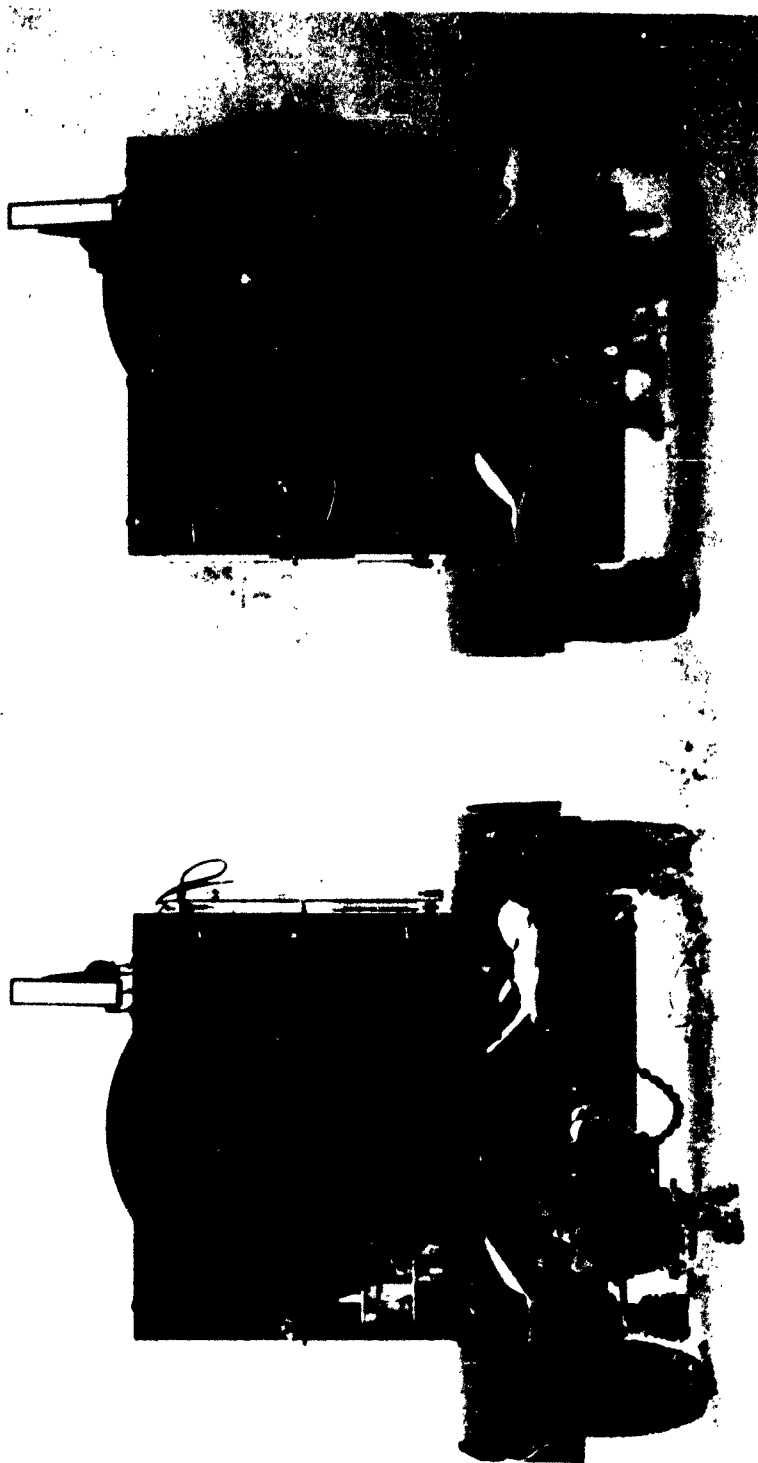


Figure 1. GSN-5A Radars

When in the cross-pointer mode of operation, the position error data are phase-advanced, filtered, and transmitted to the aircraft for excitation of the ILS glide-slope and localizer needles. The cross-pointer guided approach is accomplished through pilot control of the aircraft to maintain a zero-needle condition. The data are impressed upon the cross-pointer needles in compliance with the human factors aspects of pilot interpretation and readability. In addition, the sensitivity of the excitation signal is varied as a function of range to enable the pilot to maintain sufficient accuracy of position to permit the low approach or preflare positioning of the aircraft.

In the talkdown mode of operation, the console operator, Figure 2, visually derives the necessary commands by monitoring the position of the aircraft relative to a specified glide slope and the runway centerline. The azimuth-elevation-range (AZ-EL) oscilloscope of the AN/GSN-5A console shown in Figure 2 is used for this purpose. In addition, since identical information is presented during all modes of operation, the cross-pointer and automatic modes are supplemented with talkdown information from the operator.

The Landing Control, Central, AN/GSN-5A system is designed with the dual capability of simultaneously controlling the approach and landing of two different aircraft. Any of the three modes of operation can be used independently to control either aircraft. Also, permanent records are produced for each AN/GSN-5A system approach through the use of conventional recording equipment.

Two types of data links are employed with the AN/GSN-5A system; namely, the conventional ILS transmitter-receiver system, and the radar beacon transponder-receiver-decoder system. When using the ILS data link, the AN/GSN-5A control information is converted to an equivalent beam signal and transmitted to the aircraft on specified localizer and glide-slope radar beam to transmit guidance data to the aircraft. In the airborne equipment, the transmitted electronic signals are received, decoded, and supplied to the autopilot and/or cross-pointer needles. With either data link, the operation of the AN/GSN-5A system is the same.

The propagated beam of the K_a -band tracking radar is circularly polarized to reject backscatter from rain, snow, or fog. The radar to target range is four nautical miles in rainfall averaging 0.4 inches per hour, and is greater than this in the improved conditions of snow or fog. The radar beamwidth for all conditions is 0.5 degrees.

Either a radar beacon or a modified 3-bounce corner reflector can be used for the airborne component of the K_a -band radar. The radar beacon is a cross band receiver transponder which receives K_a -band signals and transmits S-band return signals. The return S-band signals are employed to position the K_a -band tracking radar.

The wave-off capability, designed into the AN/GSN-5A system, can be either manually initiated by the console operator or automatically initiated by the system. Automatic initiation of the wave-off command occurs when any of the following three conditions occur:

- (1) The range between two approaching aircraft decreases to a point such that the safety of either or both is impaired; the wave-off command is sent to the aircraft having the greater range.



Figure 2. GSN-5A Consoles.

(2) The aircraft exceeds the limits of an allowable altitude envelope which decreases in size with decreasing range.

(3) The aircraft exceeds the limits of an allowable lateral displacement envelope situated about the runway centerline. Manual wave-off command is initiated at the discretion of the console operator.

Figures 3 and 4 indicate photos of the exterior of the GSN-5A equipment, as located at Griffiss Air Force Base.



Figure 3. Griffiss Air Force Base Test Site.



Figure 4. GSN-5A Communications Van, Operations Van, Spares Van.

B. Test Aircraft

Three test aircraft were utilized in the Category II Program: An F-102A, KC-135, and an RB-57.

1. F-102 (Figure 5)

This was a high-performance single engine jet aircraft specially modified for automatic landing. Under FAA Contract, this aircraft was modified to include autopilot coupler changes, automatic throttle, automatic decrab, and a corner reflector. Basically, the coupler modification included removing of computation functions normally associated with the MG-10 flight control system and inserting straight amplification of ground derived functions. Thus, the autopilot can actually be utilized during the flare and landing maneuvers.

The automatic throttle was installed to provide a servo-controlled airspeed which is constant for the entire approach and is then automatically reduced for the landing maneuver. This is accomplished as follows: An electrical signal from the vertical gyro is used for pitch attitude information and an electrical signal from an airspeed transducer is used for airspeed information. These signals are summed in the servo amplifier which generates a signal to the servo actuator. The servo actuator then drives the fuel control. Switches are incorporated in the throttle linkage to disengage the automatic mode if the throttle excursion exceeds a lower limit of 70 percent engine rpm and an upper limit of 91 percent engine rpm. When the pilot engages the automatic mode, the throttle is automatically actuated by the system in response to airspeed and attitude changes of the aircraft. The attitude information is used to provide anticipation of airspeed change since the pilot or automatic landing system is now controlling the longitudinal path (altitude of the aircraft) through the elevator. The airspeed loop which operates from the airspeed transducer input is used to detect and correct for changes in the airspeed of the aircraft. An increase in attitude (nose up) shall be accompanied by an increase in thrust. An increase in airspeed shall be accompanied by a decrease in thrust.

To test the ability of the GSN-5A to land an aircraft in crosswind conditions, an automatic decrab modification was installed in the F-102. This was accomplished by installing a closed-loop servo system in the aircraft such that upon initiation from the ground station the aircraft is automatically controlled to the desired runway heading from a maximum of ± 3 degrees offset. It is necessary to institute the decrab maneuver approximately three seconds prior to actual touchdown. During decrab, it is essential that the wings remain level so that the proper touchdown roll attitude is maintained. The decrab is accomplished by a rudder displacement in conjunction with the ailerons to reduce the roll angle within acceptable small limits. As an example, assume that the F-102A aircraft has a 3 degree crab angle three seconds prior to touchdown. The crab angle will initiate a potential resulting in the difference between the J-4 compass and the ID-351 runway indicator setting. This potential, now being ϕ , is routed to the MG-10 system where the signal is properly conditioned and stored in an integrator amplifier. At decrab, the last information is stored and sent to the decrab computer. The decrab computer further modifies this signal, giving a resultant signal equal to 4 degrees of rudder for 1 degree of crab angle and a rudder time constant of one second. The instant a heading change is noted, a potential generated by the now uncaged decrab integrator is sent through the MG-10 system and is accepted by the decrab computer. This signal, now being $\Delta\phi$, is further modified by the decrab computer giving a resultant signal equal to 2 degrees of aileron per degree of heading change and 1.86 degree of aileron per degree of heading change with a lead time constant of three seconds. This process continues until the touchdown is completed.

In addition, an instrumentation system consisting of a recorder, gyros, and amplifiers was installed in the F-102. Airspeed as well as autopilot functions were permanently recorded.

The corner reflector was a 9.5 inch diameter round type reflector having a circular-polarized capability. It was mounted on the nose wheel landing door in the space normally occupied by the landing light (Figure 1).

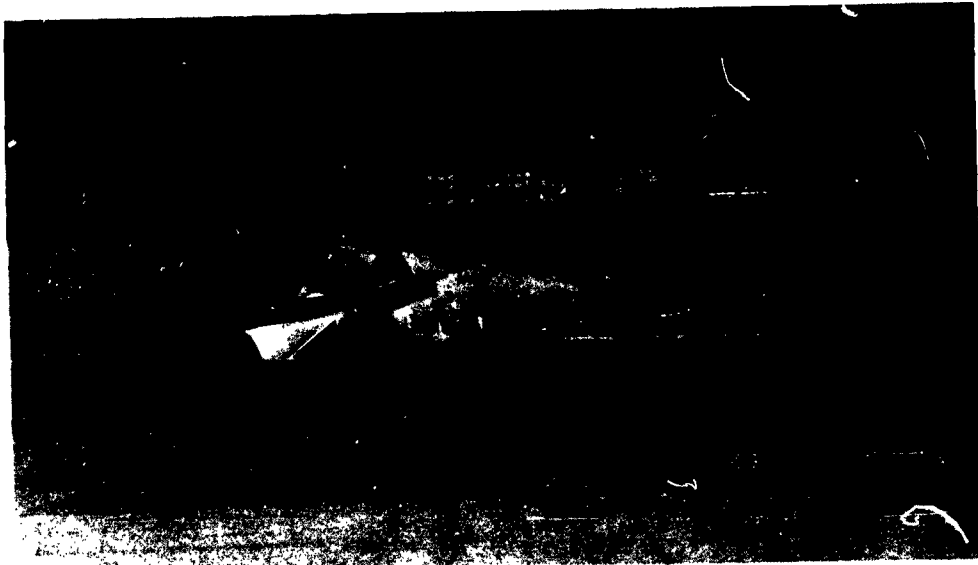


Figure 5. F-102A Test Aircraft.

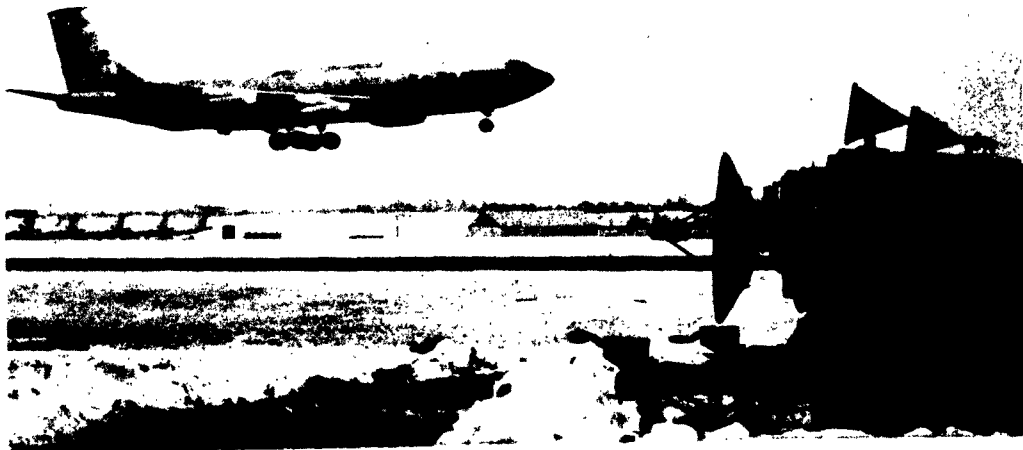


Figure 6. KC-135 Test Aircraft.

(2) KC-135 (See Figure 6)

This was a Rome Air Development Center mission aircraft assigned to this test program. It is a jet tanker converted to an electronic test bed vehicle. The installation for this program consisted of autopilot-coupler modifications, a GSN-5A beacon, a beam decoder, and a corner reflector. The autopilot mods were basically of the same type accomplished on the F-102A; that is, removing of airborne computation functions. The beacon, beam decoder was installed in the electronic equipment section of the aircraft with the associated antennas mounted within a radome on the exterior of the aircraft (Figures 7 and 8). A pilot control panel (see Figure 9) was used to allow the pilot to switch various modes of operation; that is, beacon, ALS, ILS, and normal. No auto-throttle was installed due to limitations in time and funding. The corner reflector was a 10-inch collapsible type mounted in the location of the landing light (see Figure 10). Also, an instrumentation package (Figure 11) similar to the one utilized on the F-102 was installed on the KC-135.

(3) RB-57 (See Figure 12)

The third target aircraft was an RB-57, also an RADC mission aircraft. No mods or special installations were performed on this aircraft, since it was only intended to be used on low approaches.



Figure 7. Beam Decoder as Mounted in KC-135.

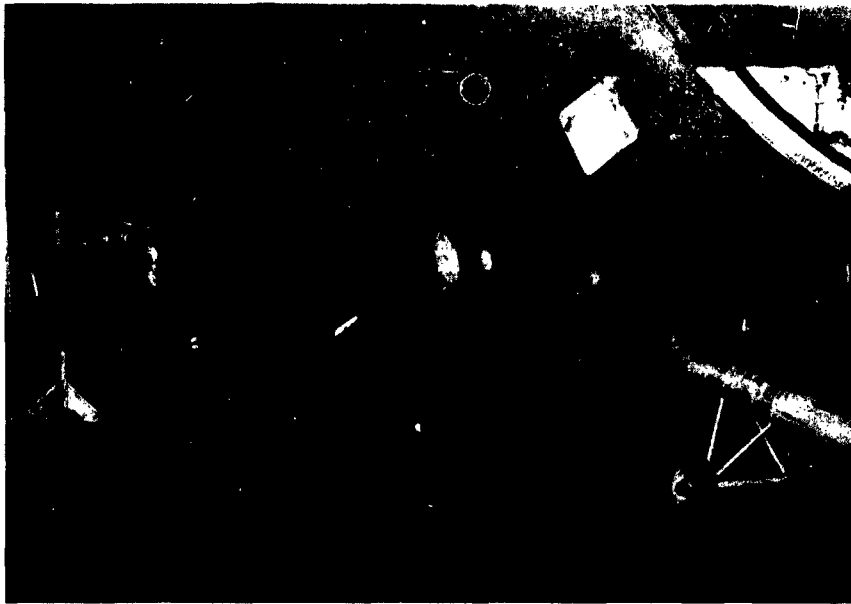


Figure 8. KC-135 GSN-5A Antenna Radome.



Figure 9. KC-135 Pilots' Instruction Panel with GSN-5A Control Switch.



Figure 10. KC-135 Pilots' Corner Reflector.

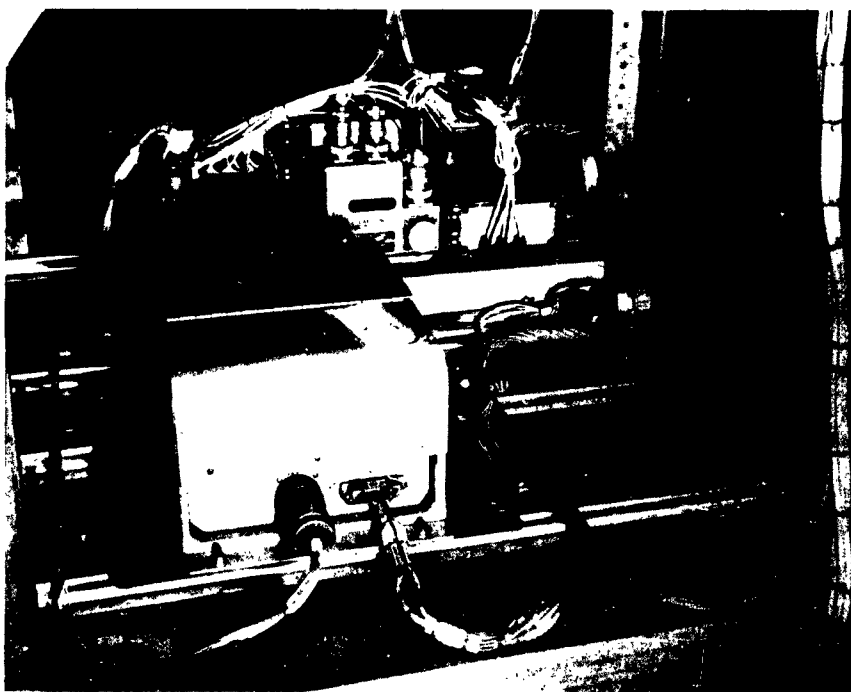


Figure 11. KC-135 Instrumentation Equipment.



Figure 12. RB-57 Test Aircraft.

III. TEST DESCRIPTION

The test objectives were documented in ESD Test Plan dated January 1962, titled: (U) "Test Plan for Category II/III Testing of AN/GSN-5A Landing Control Central." The basic technology used in the GSN-5A is identical to that used in GSN-5 (ST), an earlier developmental model. As a result of testing of this model at NAFEC and testing of the GSN-5A at the contractor's plant and McGuire Air Force Base, certain tests were deleted from the normal Category II/III testing. Therefore, the general test objectives were stated with this previous testing as background. The basic test objectives are as follows:

- a. Determine if the F-102A with automatic throttle and decrab can be automatically landed by the GSN-5A.
- b. Determine if multiple aircraft can be simultaneously controlled up to 30 seconds separation.
- c. Determine the beacon beam coding performance of the GSN-5A.

In addition, reliability, performance in foul weather, and operational suitability were evaluated.

The Category III objectives were also based on considerable prior knowledge of the equipment. Briefly, the Category III objectives were to determine operational suitability for GCA and ILS control of specific operational aircraft.

The test aircraft were a F-102A, a KC-135, and a RB-57 in Category II and a F-105, B-57, B-52, T-33, T-38, B-47, F-106, F-101, and F-100 in Category III. The F-102A was the primary automatic landing test vehicle. By the fact that it contained automatic throttle and automatic decrab, it was truly capable of performing an automatic landing. The KC-135 required manual throttle control by the pilot; however, the autopilot was automatically controlled. The RB-57, as well as all the Category III aircraft, was manually controlled through either GCA voice instruction or ILS needles. The GSN-5A was located adjacent to Runway 33 at Griffiss Air Force Base. The radar was 500 feet off centerline and 1700 feet from the end of the runway.

The instrumentation used consisted of both ground and airborne devices. In the F-102A and KC-135, a 14-channel airborne recorder was used directly to record autopilot

and data link function. Also, pilot records in the form of written comments were kept on all passes. On the ground, within the GSN-5A operations van, analog permanent records were kept on each pass. Two types of analog data were recorded, eight channel time versus function and XY plotter of range versus elevation. In addition, observers were stationed along the runway to record touchdown dispersion. A special long focal lens motion picture camera was utilized to record touchdown vertical velocity of the instrumented aircraft (See Appendix). The camera and observers were the main methods of evaluating touchdown performance. Path control and vertical velocity data was also obtained from the GSN-5A recordings.

A checkout period of approximately one month was required to complete mating checks of the F-102A to the GSN-5A. During this period, limited test data was obtained due to many changes and modifications. The basic effort performed during the debugging period was a dynamic verification of the theoretically derived gains for this type of aircraft. In most cases, the experimental agreed with the theoretical. One of the important control techniques found useful during this period was a throttle chop prior to touchdown. Originally auto-throttle was used up to flare, then air speed was frozen until touchdown. This tended to cause long touchdowns or floaters. Therefore, this was changed to freeze airspeed only until decrab, three seconds from touchdown; then the throttle was chopped to 68 percent rpm until touchdown. This prevented the floaters and provided for a more accurate landing. The F-102A autopilot airframe response was very tight; thus a smooth control through touchdown was possible. The loop time constant was found to be 0.2 seconds in both roll and pitch.

In the early phases of checkout, several passes were made to determine the optimum use of the speed brakes during the level portion of the flight. It was determined that when the ambient temperature was below 35 degrees, the speed brakes could be left out throughout the entire pass. At temperatures over 35 degrees, it was necessary to keep the speed brakes in until glide slope intercept since an excess of 90 percent rpm was required to maintain 175 knots approach speed.

As compared to the theoretical gains required for the auto-throttle during the simulation studies, it was necessary to increase the gain approximately three times. This was due to the width of the hysteresis loop in the present F-102A. After this change, the auto-throttle performed satisfactorily. Its response to a 2-degree step command was up to 90 percent within 17 seconds with a 0.6 second time lag, which was adequate for GSN-5A control.

The debugging of the KC-135 was accomplished in the ILS mode over a period of approximately two weeks. The time constant of its autopilot airframe combination was approximately 0.3 seconds in both channels.

The reference height of the runway had to be compensated for in the computer due to a $4\frac{1}{1000}$ ' longitudinal drop in the surface and $1.5\frac{1}{150}$ ' drop laterally in the area of touchdown. Also, at three seconds prior to touchdown, a fixed flydown ramp of one degree/second was sent to the aircraft to compensate for the cushioning effect of the surface air.

Additional switching charges were incorporated to insure all commands were initiated or frozen simultaneously. The gains were set and fixed on both aircraft. From this time on, extensive data was taken on each pass.

Polarad "A"-scope pictures were taken in various weather conditions. However, no heavy precipitation and aircraft targets were ever available at the same time to get conclusive results (Figure 13).

Static ground-to-ground beacon data checks were accomplished. A complete airborne installation was mounted in a truck and used as a test vehicle. Commands and discretes were sent to the test vehicle prior to check calibration and reliability. Also, tracking of the test vehicle gave an indication of the beacon radar tracking problems. Due to the limited time available in the KC-135, the beacon equipped aircraft, only limited flight checks of the beacon data link were possible.

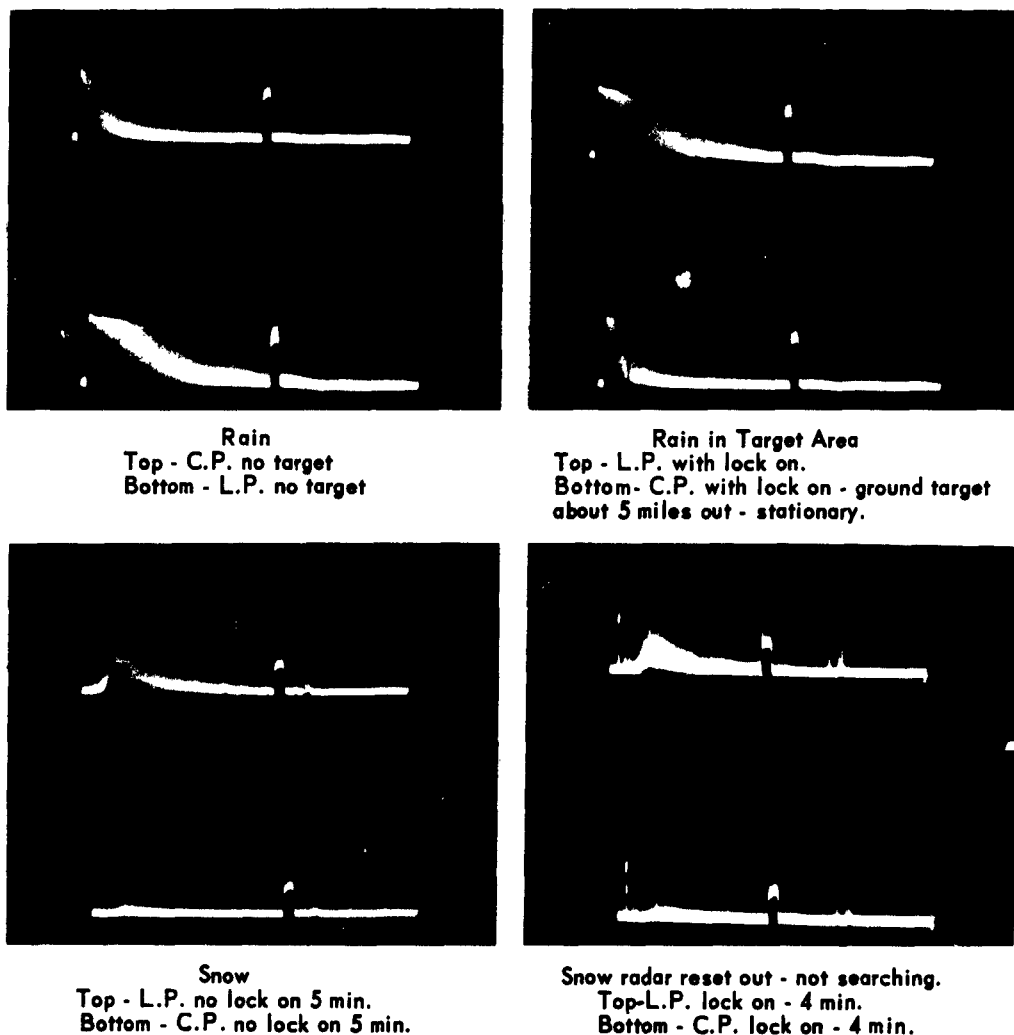


Figure 13. Rain and Snow Test.

IV. RESULTS

The following results form a basis for the conclusions reached in the following section.

A. Landing Dispersion

The dispersions recorded for the F-102A are indicated in Figure 4. The GSN-5A Exhibit calls for one sigma limit of ± 200 feet or 67 percent of all landings be within a 400-foot length on the runway. As seen by Figure 14, a few landings exceeded this limit; however, the percentage was below 33 percent allowable. The data also shows a tendency to be on the long side. This is due to the flare glide path used and the lifting effect of the wings at low altitude (cushioning effect). By using a steeper flare path, this dispersion possibly would be more evenly distributed; however, the danger of having a high impact landing also would be greater. Also, it is more desirable, operationally, to have longer, softer landings than to try to hit a prescribed point on the runway. The general pilot's opinion is that the optimum landing point is different for every aircraft and breaking condition.

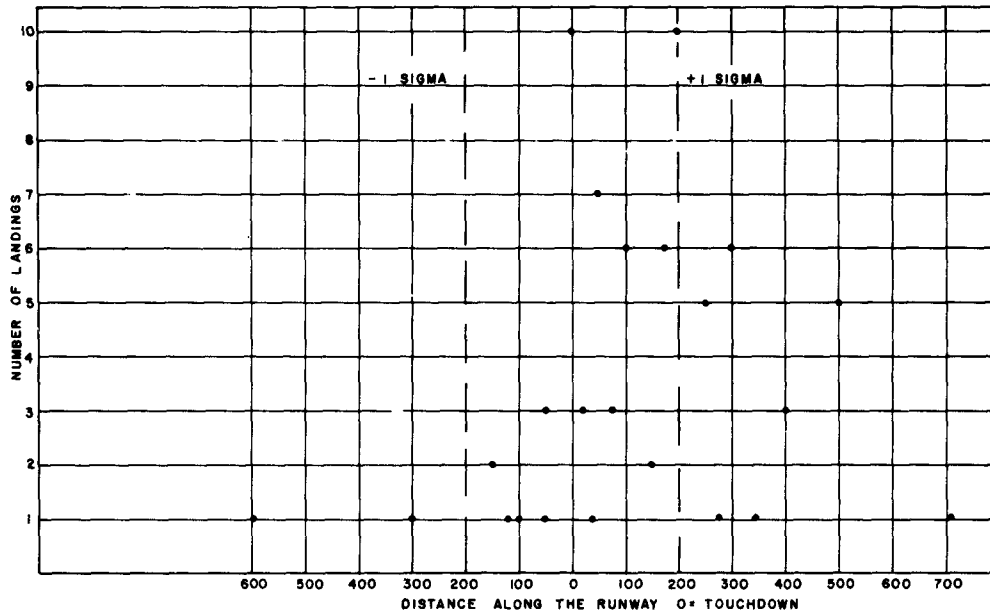


Figure 14. F-102A Landing Dispersions.

Figure 15 indicates the KC-135 dispersions. As in the case of the F-102A, there is a tendency for long, rather than short landings. The data on this aircraft is multiplied by the fact that the pilot is chopping throttle at a prescribed signal rather than automatically as in the case of the F-102A. This factor of human timing affects the KC-135 data. The decrab light in the aircraft was used as the throttle signal in the KC-135. As noted by the figure, all the landings were within allowable percentage spread.

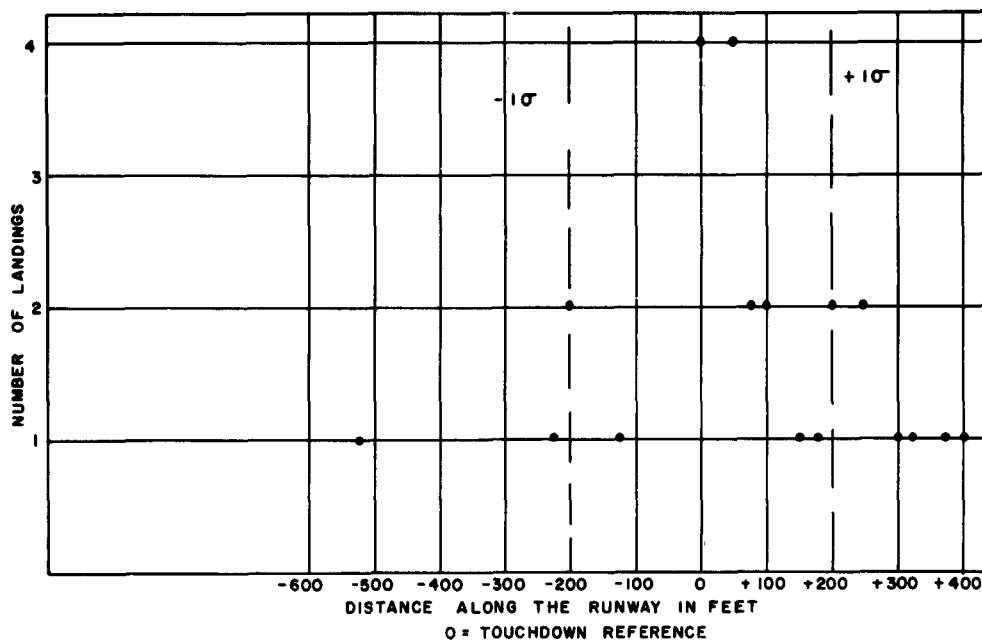


Figure 15. KC-135 Landing Dispersions.

B. Vertical Velocity

The GSN-5A Exhibit calls for a ± 1 sigma value of one foot per second with a mean of two feet per second on the F-102A. Limited data was obtained on the sink-speed camera due to weather conditions; however, agreement was shown between XY and camera data. Landing speed is required to determine vertical velocity from the XY plots. This was assumed to be an average value of 114 knots for the KC-135 and 163 knots for the F-102A. However, an error of ten feet per second in horizontal speed would give only an error of 0.1 feet/second in vertical speed. Therefore, the XY plots give a reasonable indication of sink speed. From visual observations, the XY data and pilot comments, a majority of the automatic landings were successful and within tolerable limits.

The KC-135 sink speeds were observed in a similar manner. They were considered successful and within tolerable limits. However, the overall pilot's opinion and safety considerations indicated a preference for a longer allowable landing dispersion with a recomputed flare point as a function of aircraft vertical error.

C. Multiple Aircraft Data

The weather and local flight conditions prevented extensive test of this item; however, sufficient data was obtained to indicate the system's capabilities. The numbers, types and landing separations are noted in Table I. The landing separation was the time between successive passes by each aircraft over the preselected touchdown

point on the runway. In some cases, where the aircraft was at 20 feet altitude over this point, the time was still noted. The reasons for the altitude were the lack of adequate high-speed turn-off existing at Griffiss Air Force Base, and to prevent delays in the flight pattern. Of special interest it was noted that the prop wash behind the KC-135 was too severe even at two miles' separation to allow the RB-57 or F-102A to safely continue. Thus, the design goal of 30-second separation would not be practical for multiple KC-135 type of aircraft. After very little training, the pilots were able to hold their timing to as little as 35 seconds. No RAPCON vectoring was attempted on multiple approaches and all multiple approaches were accomplished VFR. In all cases, the GSN-5A continued to track the correct aircraft and lock-on the third aircraft. Some difficulty would be experienced in IFR operator procedures due to the limited communication switching within the GSN-5A and netting to the Tower and RAPCON. However, two operators had very little difficulty in acquiring 35-second rate targets. The automatic closure wave-off feature was dramatically demonstrated. When pilots tried to close the gap, the wave-off would signal if they exceeded the preset limits (6000 feet minimum, 30,000 feet maximum). A fourth aircraft, an aero-commander, was also flown in the pattern with no difficulties.

D. Path Control

Since no theodolites were available for a true independent measure of the aircraft path in space, the GSN-5A ground records and pilot comments were used as evaluation aids. The flight path computer sets upper and lower boundary limits, which are very stringent at low altitudes; thus, a wave-off indicated that the aircraft was not being controlled within desired boundaries. Figure 16 indicates the boundary limits utilized during the program. Table 2 indicates the results of flights taken from the GSN-5A, 8-channel recorder using the alt-error channel at a 12,000 foot range slice. All of the approaches were very close to the desired path.

The flare initiate point, approximately 50 feet in altitude, is a very critical control point. Past studies by Bell Aerosystems Company have indicated that with a typical response autopilot, an aircraft must be within +5 -3 feet of the correct altitude at that point. If he is not, the flared landing cannot be safely achieved. This rule proved very valid during the test program. Some wide angle captures were tried with the F-102A. The autopilot preset bank limits prevented extensive testing of this type.

E. Weather Test

The results of a study of the K_a -band GSN-5A beam propagation through precipitation have indicated that, in theory, the maximum range of four nautical miles will be obtained during a rainfall of ten millimeters an hour if the radar were polarized circularly. No tests were possible with a target aircraft during such rain conditions at GAFB or NAFEC. Therefore, the theoretical data has not been experimentally verified. Figure 13 indicates A-Scope pictures taken at GAFB during light-to-medium rain conditions (2 - 5 mm per hour) with the effect of circular polarization. Figure 13 also indicates the relative performance of the GSN-5A during snow conditions, with the associated improvement.

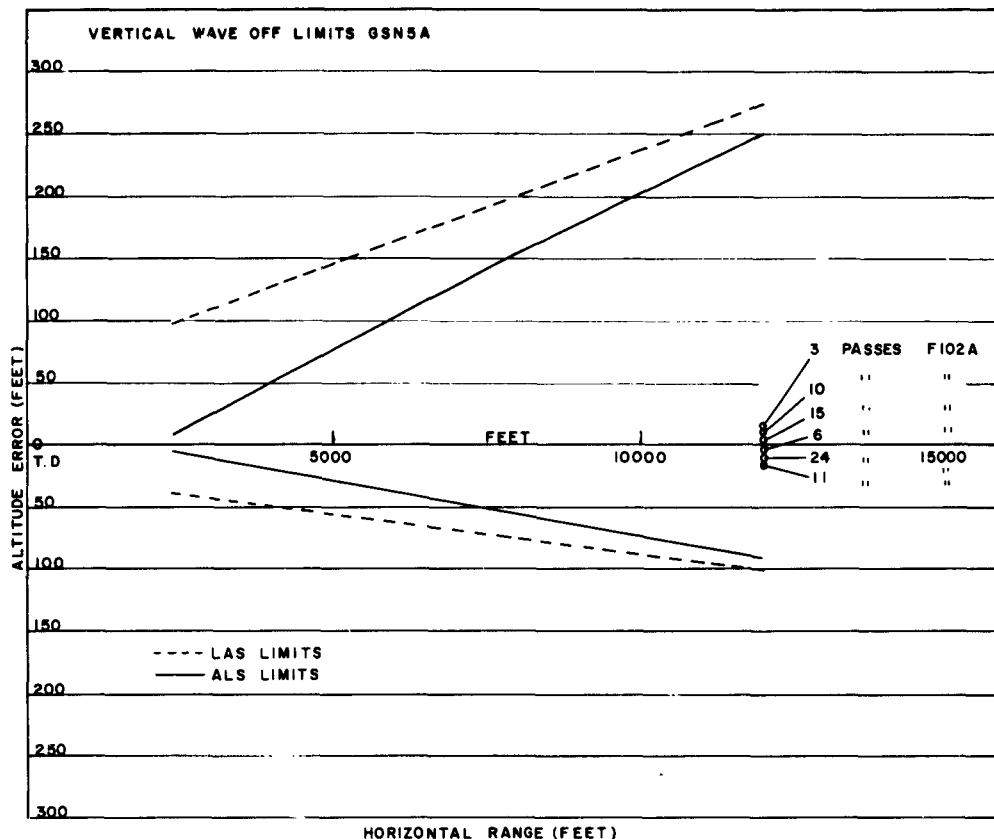


Figure 16. GSN-5A Path Boundary Limits with Passes Superimposed.

The corner reflector on the aircraft must be circularly polarized to achieve the maximum effect. Ten millimeter per hour is not an especially heavy rain and by no means is a downpour. Therefore, it cannot be concluded that the 4-mile range will be consistently obtained during heavy rainfall conditions.

A note on the ten mm/hr rate - In Washington DC, statistics indicate the rain equals or exceeds this rate 0.2 percent of the time or 17 hrs/yr. The location in the U.S. where this rain is a maximum is New Orleans, or Gulf Coast area. In this location, the rain exceeds ten mm/hr, 0.6 percent of the time or 53 days per year. In other areas of the world, this time could be even higher. Thus, if the GSN-5A was installed in New Orleans it would theoretically be off the air 53 days per year due to weather alone.

The Category III results, Table 2, have been reported in AFCS report entitled: "Category III Operational Test and Evaluation AN/GSN-5A." In general, the results were good on reliability and strong with recommendations for equipment changes before the equipment becomes operational. The main objection was the short range of the system.

A minimum of ten miles was recommended.

Chronological flight summary tables are located in the Appendix for both Category II and III tests.

V. CONCLUSIONS

The equipment is basically sound and satisfactorily performs all the functions it was designed for. The beacon/decoder data was not as complete as desired; however, past tests on this technique as well as limited data obtained at RADC indicate that the principle is valid and that automatic landings can be made with such a device. In comparison of the beacon versus ILS corner reflector mode, there is very little difference in the quality of control. The main advantages of the beacon over the ILS are the increased radar range, dual aircraft capability, and more diversified command structure.

The quality of control through landing as well as approach was generally good on both automatic aircraft. In no case was any aircraft placed in a dangerous position or landed with too severe an impact. This was primarily due to the control limits set by the computer. For instance, if the aircraft was not within three or five feet of the glide path at flare initial point (50 feet altitude), it was automatically waved off. The dual aircraft results (Table I) indicated that the system would have no difficulty in accepting two landing aircraft at the specified 120 aircraft hour rate. However, the operational problems in the control van as well as the feeder would limit a sustained operation of this type. No cross-track interference was observed between the radars or ILS transmitters. Interference was observed between the GAFB ILS monitor/receiver and the GSN-5A UHF voice and data-link transmitters. The solution is to reduce the GSN-5A power and/or move to a different location. The beacon and ILS modes of control were never simultaneously on during a dual aircraft approach due to limited time and poor weather; however, no interference is expected in this case. In the dual manual approach tried during Category III with two F-101's making a side-by-side approach, the radars remained locked-on to the proper aircraft. This type of approach would require more data to make a firm conclusion, since both aircraft could be in the range gate simultaneously and cross track could occur. The pilots' opinion on such an approach was that due to the short final, formation flights on the GSN-5A are unsafe or very difficult due to the high maneuvering required at low altitudes.

The general conclusion regarding the manual GCA/ILS mode of operation is that the system is good to a lower limit of 200 feet and 1/2-mile. Beyond this point, the scintillation may cause the radar to produce large errors. Also, the AZ-EL indicator was not considered accurate enough at close ranges for close in GCA control.

A. Conclusions - F-102A

1. The safe automatic landing of an F-102A via GSN-5A is feasible and possible.
2. Auto-throttle is highly desirable on this type of aircraft; ± 1 knot variation airspeed is obtainable with a time constant of 0.7 seconds.
3. Auto-decrab was successfully demonstrated; however, no tests were possible in gusty cross winds or high steady cross winds to fully demonstrate its dynamic response.

4. The automatic mode of control had an overall response time of 0.3 seconds. This system was very responsive to transient changes due to gusts and the flare-out control was consistently good. Very little maintenance was required on the autopilot. However, the ILS receiver and coupler did give trouble in calibration drift and overall reliability.

5. The F-102A corner reflector had sufficient gain to maintain a constant tracker reference. A greater tilt angle would be more desirable to compensate for narrow runway siting situations.

B. Conclusions - KC-135

1. A safe automatic landing can be accomplished on this aircraft using the GSN-5A.
2. The aircraft-autopilot combination had an easily adaptable response characteristic and required very little checkout and calibration for the GSN-5A tie-in.

3. The ILS mode was produced on overall pitch response of 0.4 seconds. The aircraft path control was dynamically stable in both pitch and bank.

4. Beacon tracks were successful to a range of 30,000 feet. No flights were possible using the decoder. However, the decoder was mounted in a remote location from the GSN-5A and successful command discrete signal transmissions were accomplished. The aircraft antenna installation was unsatisfactory due to a condensation problem. This could be alleviated by either venting the waveguide or planting preheaters in the radome.

5. The corner reflector was satisfactory. The overall ground equipment reliability is between 85 and 90 percent. Due to the exposed nature of the radars and the cramped control van, some maintenance difficulties are encountered in this system. Logistic support also is a problem due to the nonavailability of recent solid-state standardized parts and several specialized parts within the equipment. The frequency of the radar is rather unusual, causing some of the logistic problems.

The safety of flight features of the system are adequate. An ILS monitor and system calibration method would be an enhancement. The main wave-off initiation complex is very satisfactory. If the pilot loses lock-on during an ILS approach, additional cockpit signals should be provided.

In addition, the following design deficiencies were observed:

1. The AN/GRC-27 radio equipment required the greatest maintenance time and should be replaced by a smaller, more reliable equipment.

2. Exposure of radar trailers in foul weather conditions would cause serious difficulty in maintaining the radars.

3. The single phase power system was not a standard Air Force connection; therefore, substitution of power sources was extremely difficult. A 3-phase, 4-wire system should be used on future equipments.

4. Tower rings for the radar trailers are too low for normal Air Force vehicles. This required a minimum of two different types of vehicles to move the equipment.

5. The antenna resolver adjustments are too critical and lack sufficient test points.

6. The location of the exterior cable jacks should be changed.
7. There is no method for the controller to check the alignment of the centerline and slide slope reference during an approach. Present alignment can only be accomplished prior to lock-on.
8. The AZ-EL indicator lacks accuracy at close-in ranges. Also, insufficient number of range marks are provided. The overall presentation is unstable and requires extensive adjustment.
9. Further minor design deficiencies are listed in the AFCS Category III report.

VI. RECOMMENDATIONS

A. General

1. Increased range should be provided sufficient for a 10-mile final approach in heavy rain.
2. An AZ-EL scope presentation, similar to the AN/SPN-10 presentation, should replace the present scopes. The recommended scope is a 3-gun tube, which includes the "A"-scope true-video, and is logarithmic with very fine lines representing glideslope and centerline. Accuracy should be greater (for GCA approaches) than is possible with the PAR scope now being used.
3. When making an ILS approach and a wave-off occurs, flags should appear on the pilot's ILS indicator, or some other very definite indication should be given the pilot. Reliance on voice transmission alone is not sufficient.
4. The communications equipment should be improved or designed to:
 - a. provide the controller with a communications control panel compatible with present ATC systems, and to
 - b. provide low-power, ILS data-link transmitters with adequate reliability, filtering and antenna directivity to prevent interference with other transmitting, receiving, or monitoring equipment located nearby.

B. Specific Recommendations for Design Improvement

1. *Power for the System*

- a. It is recommended that stable commercial power be provided at all operational sites for the system. This should be backed-up with a reliable diesel unit. If commercial power is not feasible, two reliable diesel units should be provided and should be used alternately.

- b. The power system should be changed to a 3-phase, 4-wire system, which is common throughout the Air Force. This is strongly recommended, even if a load balancing device proves necessary. The single phase system is somewhat unique and in case of failure, substitution is extremely difficult.

2. *Pindle ring mounts for towing the trailers:* Recommend all pindle rings on all vehicles be adjustable so that they can be matched to the height of the available towing vehicle's pindle hook.

3. *Marking of power and signal cables:* All of the interconnecting cables should be marked at each end to correspond with similarly marked plugs.

4. *Location of cable jacks:* The cable jacks located at the top corners of the trailers should be relocated at the bottom of the trailers, out of the way of door openings or other fixtures.

5. *Access to trailer roof(s):* Ladders should be permanently mounted on the end of the trailers to provide a safe access to the trailer roofs.

6. *Radar trailer leveling-jack tool:* An impact drive tool, reversible, with a flexible fitting for the jack drive shafts should be provided as part of the equipment.

7. *Alignment and checkout:* Technical Orders and Maintenance Instructions should be written. They should contain step-by-step alignment instructions, written for use by S-level radar technicians.

8. *Recommend the resolver adjusting task be made a simpler, one-man job by:*

- a. providing voltage test-points near the front of the trailer,
- b. providing a place to set the "Fluke" Null-voltmeter so that it can be read while resolvers are being set, and
- c. providing vernier type controls, with a locking device, for setting the resolvers instead of the splined wrench.

C. Major Configuration Changes

1. One approach is for a complete change of the system packaging to resolve exposed radar condition and limited operator space. A configuration similar to the current production, AN/SPN-10 is an example of this concept wherein both radars are enclosed. This would be a dual system with improved data link and automatic landing capability.

2. Another possible system configuration for more tactical operations would be to mount a single-channel system in a helicopter, such that it can either be operated from within the parked helicopter or removed for operation. The proposed use of such a configuration would be for only GCA or ILS approaches; thus, the landing computer would not be required. Also, to achieve such a configuration, additional manipulation and use of solid-state techniques would be required over the present GSN-5A.

3. Addition of a simple feeder system to the basic landing system. The feeder capability should be modular in type, such that it could be removed for installations where an existing feeder is operational. By having a feeder capability, a GSN-5A type system could be moved into a remote site and could provide complete air traffic control services. Example of a beacon-type feeder would be to use IFF components in the ground and aircraft with a PPI presentation. This would be an inexpensive method, however, it would be useful only on IFF equipped aircraft. A more versatile system would be a normal search radar using the latest solid-state advanced radar techniques.

D. Recommended Approach

To achieve the above recommendations, it is conceivable that some design problems will occur. This is especially true in trying to achieve an accurate 10-mile all-weather tracking radar. A new frequency will be required to achieve the weather

capabilities with the associated antenna and new transmitter. To better understand and verify the extended range, it is recommended an experimental system at the new frequency be fabricated. By using basic components of the GSN-5A, such as the antenna servo, power supplies, computer, and so forth, and adding a new transmitter and antenna and an AN/SPN-10 indicator, a modest cost experimental system could be fabricated and demonstrated.

A more advanced major configuration change would be elimination of the limited target tracking and mechanical scan problems of the GSN-5A by the addition of an electronically steerable array with a raster scanning pencil beam or fan beam. The coverage of such an array should be equal to or greater than the present GCA radar limits. Its range, weather, and low-angle tracking capabilities should be comparable to the advanced tracking concept as outlined in paragraph D above. In addition, low-cost multiple target tracking circuits would be required for rejection of clutter and automatic control and ILS data link purposes. Raw video for AZ-EL display also should be provided as needed. The volume scanning system would provide the operator data on all targets within the landing zone instead of only the target under control as in present system. In addition, the system would provide fixed ground targets for reference and continuous calibration during every approach.

Similar array and track while scan techniques are available from AF and other programs which could be adapted to implement the above volume coverage system. It is recommended that a design study be initiated to determine the best design for such a system and also compare its cost and complexity to the proposed longer range present tracking approach.

VII. APPENDIX

TABLE 1

MULTIPLE AIRCRAFT TEST						
FIRST AIRCRAFT		2ND AIRCRAFT		3RD AIRCRAFT		SEPARATION
TYPE	MODE OF CONTROL	TYPE	MODE OF CONTROL	TYPE	MODE OF CONTROL	
	11/30/62					
F-102A	ALS TD	B-57	ILS WO	--	--	--
						WO due to a/c too close; limit set at 12,000'
F-102A	ALS TD	B-57	ILS LA	--	--	55 sec
F-102A	ALS LA	B-57	ILS LA	--	--	6 mi
F-102A	ALS TD	B-57	ILS LA	--	--	4.5 mi
F-102A	ALS TD	B-57	ILS LA	--	--	6 mi
F-102A	ALS TD	B-57	ILS LA	--	--	75 sec
KC-135	ALS LA	B-57	ILS LA	--	--	95 sec
						Turbulence problem behind KC-135
B-57	ILS LA	KC-135	LA	--	--	7 mi
B-57	ILS LA	KC-135	LA	Aero-Commander	ALS TD	4.5 mi
						Between each aircraft
B-57	ILS LA	KC-135	LA	Aero-Commander	ALS	75 sec
						Between each aircraft
B-57	ILS LA	KC-135	WO			Auto overtake
B-57	ILS LA	KC-135	TD	Aero-Commander	ALS	5.5 mi
						Between each a/c
	12/3/62					
B-57	ILS LA	KC-135	LA	--	--	65 sec
B-57	ILS LA	KC-135	LA	--	--	45 sec
B-57	ILS LA	KC-135	WO	--	--	
						Auto overtake; separation less than 8000'
B-57	ILS LA	KC-135	TD	--	--	40 sec
B-57	ILS LA	KC-135	TD	--	--	40 sec
B-57	ILS LA	KC-135	TD	--	--	35 sec
	12/11/62					
B-57	ILS LA	KC-135	LA	--	--	60 sec
B-57	ILS LA	KC-135	TD	--	--	60 sec
B-57	ILS LA	KC-135	TD	--	--	68 sec
B-57	ILS LA	KC-135	TD	--	--	40 sec

TABLE 2

SCHEDULE OF CATEGORY III RUNS						
TYPE OF AIRCRAFT	DATE	TOTAL RUNS	PAR	ILS COUPLED	ILS MANUAL	REMARKS
B-47	8 May 62	6	6			
B-47	10 May 62	6		3	3	
B-52	10 May 62	8	4	2*	2	*Coupled in Localiser only
B-52	6 Jul 62	2		1	1	
F-106	16 May 62	6	2		4	
F-106	17 May 62	4	2		2	
F-101	15 May 62	6	3	1	2	*ILS Manual Formation
F-101	17 May 62	6	1	2	3	
F-101	5 Jul 62	10	1	5	1*	
T-38	25 May 62	14	4		7	2-missed lock-on, 1 broke off, a/c not equipped for coupled-ILS.
T-33	25 May 62	10	4		6	A/C has no autopilot
F-105	29 May 62	10	4		6	A/C could not engage coupler
RB-47	10 Jul 62	8	2		6	
F-100	18 Jul 62	8	3		5	
		104	36	14	48	

TABLE 3

F-102A FLIGHT SUMMARY					
DATE	LOW APPROACHES	TD TRIES	TD ACCOMPLISHED	NON-TRAFFIC WAVE-OFF	REMARKS
8-24-62 thru 9-25-62		0			70 passes flown for calibration and checkout purposes. No td were attempted.
9-26-62	13	2		1	Too low in flare; pilot took over.
10-2-62	12	7	1	6	Floaters.
10-4-62	1	1		1	
10-8-62	8				Re-check aircraft response.
10-10-62	4				Re-check aircraft response.
10-11-62	2				Closed loop to 50 feet altitude.
10-15-62	5				
10-17-62	7	6	4	2	Auto-throttle disengaged and radar unlocked.
10-18-62	6	4		4	Radar unlocked and radar servo response down.
10-19-62	3	4		4	Radar unlock
10-20-62	5	9	2	7	Floaters
10-22-62	4	5	3		
10-24-62		2	2		
10-29-62	4	8	8		Manual throttle chop used at decrab signal.
10-30-62	5				From here on, either manual or automatic throttle chop was used.
10-31-62	1	1		1	Pilot error.
11-1-62	6	10	10		Auto-throttle chop now installed.
11-3-62	3	7	7		
11-8-62	4	7	7		
11-9-62	2	3	3		
11-14-62	6	5	3	2	Magnetron failure
11-15-62	3	7	5	2	
11-19-62		1	1		
11-27-62	2	4	4		
11-28-62	2	4	3	1	Manual landing ILS; coupler would not engage.
11-29-62	5	5	4	1	Manual landing ILS; coupler would not engage.
11-30-62	2	8	8		
12-14-62	1	4	1	3	Acquisition offset too large for autopilot limits.
12-20-62	3	3	2	1	Acquisition offset too large for autopilot limits.
END OF FORMAL CATEGORY II TESTING					
1-9-63		6	6		Demonstration to 431L
1-11-63		2	2		Demonstration to Press.
TOTALS	119	125	88	36	

TABLE 4

KC-135 FLIGHT SUMMARY							
DATE	LOW APPROACHES	TD TRIES	TD ACCOMPLISHED	NON-TRAFFIC WAVE-OFF	TRACK REF	CONTROL MODE	REMARKS
11-1-62	10	1	1		C.R.	ILS	
11-2-62	5	4	3	1	C.R.	ILS	Pilot took over - too low.
11-5-62	2	2	2		C.R.	ILS	
11-8-62	2	5	5		C.R.	ILS	
11-14-62	10	3	3		C.R.	ILS	
11-30-62	7	7	7		C.R.	ILS	
12-3-62	5	3	3		C.R.	ILS	
12-4-62	2	2	0		Beacon	ILS	No reply from beacon
12-11-62	5	5	5		C.R.	ILS	
12-11-62		2	0		Beacon	ILS	No reply from beacon
12-13-62	8	1	1		C.R.	ILS	
12-13-62		2	0		Beacon	ILS	No reply.
12-20-62	11				Beacon	ILS	Reply to 30,000 feet.
12-20-62	1				Beacon	Decoder	Decoder intermittent.
TOTALS	68	37	30	1			Condensation in waveguide caused the failure of the beacon and time limited further test of decoder.



Figure 17. Sink Speed Camera.

CATALOGUE FILE CARD

<p>Rome Air Development Center, Griffiss AF Base, N.Y. Rpt No. RADC-TDR-63-166. CATEGORY II/III TEST OF THE AN/GSN-5A. Apr 63, 28p, incl illus, tables.</p> <p>Unclassified Report</p> <p>The Landing Control, Central, AN/GSN-5A is a ground-based, final approach navigation system providing three basic approach and landing techniques. These include completely automatic control, cross-pointer guided approach and talkdown. These techniques used singularly or in combination maintain aircraft surveillance and guidance information to touchdown.</p> <p>Test aircraft used in the Category II Program were an F-102A, KC-135, and an RB-57. In Category III test aircraft were an F-105, B-57, B-52, T-33, T-38, B-47, F-106, and an F-100. The F-102A was the primary automatic landing test vehicle.</p> <p>Test results are presented in the form of graphs, tables, and general comments and form a basis for the conclusions and recommendations.</p>	<p>1. Approach techniques 2. Landing techniques I. System 431L II. Prichard, J.R. III. In DDC collection</p>	<p>Rome Air Development Center, Griffiss AF Base, N.Y. Rpt No. RADC-TDR-63-166. CATEGORY II/III TEST OF THE AN/GSN-5A. Apr 63, 28p, incl illus, tables.</p> <p>Unclassified Report</p> <p>The Landing Control, Central, AN/GSN-5A is a ground-based, final approach navigation system providing three basic approach and landing techniques. These include completely automatic control, cross-pointer guided approach and talkdown. These techniques used singularly or in combination maintain aircraft surveillance and guidance information to touchdown.</p> <p>Test aircraft used in the Category II Program were an F-102A, KC-135, and an RB-57. In Category III test aircraft were an F-105, B-57, B-52, T-33, T-38, B-47, F-106, F-101, and an F-100. The F-102A was the primary automatic landing test vehicle.</p> <p>Test results are presented in the form of graphs, tables and general comments and form a basis for the conclusions and recommendations.</p>	<p>1. Approach techniques 2. Landing techniques I. System 431L II. Prichard, J.R. III. In DDC collection</p>
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